NASA TECHNICAL MEMORANDUM

NASA TM X-1159

C9

NASA TM X-1159

SUMMARY OF AN ADVANCED MANNED LIFTING ENTRY VEHICLE STUDY

by Robert W. Rainey

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • OCTOBER 1965

UNCLASSIFIED

~~CONFIDENTIAL~~

NASA TM X-1159

SUMMARY OF AN ADVANCED MANNED LIFTING ENTRY VEHICLE STUDY

By Robert W. Rainey

Langley Research Center
Langley Station, Hampton, Va.

CLASSIFICATION CHANGE

UNCLASSIFIED

To ....

By Authority of C-STAR Dated 12-31-70
J. 8. No. 24

Changed by D.X.C. .... Date 10-21-88

GROUP 4
Downgraded at 3 year intervals;
declassified after 12 years

CLASSIFIED DOCUMENT–TITLE UNCLASSIFIED

This material contains information affecting the national defense of the United States within the meaning of the espionage laws, Title 18, U.S.C., Secs. 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

NOTICE

This document should not be returned after it has satisfied your requirements. It may be disposed of in accordance with your local security regulations or the appropriate provisions of the Industrial Security Manual for Safe-Guarding Classified Information.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

~~CONFIDENTIAL~~

UNCLASSIFIED

UNCLASSIFIED

[redacted]

SUMMARY OF AN ADVANCED MANNED LIFTING ENTRY VEHICLE STUDY* **

By Robert W. Rainey
Langley Research Center

SUMMARY

At the Langley Research Center a broadly based study is underway of a class of advanced manned lifting entry vehicles with a hypersonic maximum lift-drag ratio slightly in excess of 1. From this study has emerged a configuration designated HL-10 (horizontal lander 10) that meets the research guidelines chosen during the early phases of the study. Many problems, their possible solutions, and compromises have been revealed; several in the areas of aerodynamics, heating, handling qualities, and ground and water landing are discussed herein. Some of these are not peculiar to this specific class of vehicle but apply to other classes as well.

INTRODUCTION

Recent studies have indicated that an entry vehicle with a hypersonic maximum lift-drag ratio of about 1 merits serious consideration in the determination of how entry vehicles may best meet the requirements of future space missions (refs. 1, 2, and 3). Consequently a generalized study was undertaken at Langley Research Center to identify the various problem areas associated with this class of vehicle, to identify possible solutions of the problems, and to develop a feasible complete configuration for specific studies. The purpose of this paper is to summarize the study areas, the research guidelines, and some of the highlights of the study, including some of the problems and their solutions.

SYMBOLS

The units used for the physical quantities defined in this paper are given both in the U.S. Customary Units and in the International System of Units (SI). (See ref. 4.)

---

*Some of the material in this report was originally presented at a closed session of the Entry Technology Conference held by the American Institute of Aeronautics and Astronautics, Williamsburg/Hampton, Virginia, Oct. 12-14, 1964.

**Title, Unclassified.

[redacted]

UNCLASSIFIED

b wing span, ft (m)

C_L lift coefficient

C_m pitching-moment coefficient

C_{n_β} directional-stability parameter

L/D lift-drag ratio

l model length, ft (m)

M Mach number

Q total heat load, Btu (J)

$\dot{q}$ heating rate, Btu/ft^2-sec (W/m^2)

R_l Reynolds number based on model length

V_E entry velocity at 400 000-foot altitude (121 920 m), ft/sec (m/sec)

x,y model coordinates

α angle of attack, deg

δ_e elevon deflection, deg

STUDY AREAS

The study areas which have received attention to date are as follows:

(1) Trajectories and entry environment

(2) Static aerodynamics

(3) Launch-vehicle compatibility

(4) Heat transfer

(5) Pressure distribution

(6) Structures and thermal protection

(7) Landing-gear design

(8) Visibility and internal arrangement

(9) Dynamic stability and control

(10) Handling qualities

(11) Conventional and emergency landing

(12) Protruding canopy installations

Material discussed in this paper is limited almost entirely to the areas of aerodynamics, heating, handling qualities, and ground and water landing.

RESEARCH GUIDELINES AND BASIC VEHICLE

At the start of this study the operational aspects of the lifting-body vehicle were reviewed and certain guidelines were chosen. These guidelines are as follows:

(1) A trimmed hypersonic lift-drag ratio of about 1 without elevon deflection to avoid additional local heating problems in the vicinity of the elevons

(2) A high trimmed-lift capability at hypersonic speeds to provide relatively high pull-out altitudes and possible reduction in overall heating during entry and abort

(3) A subsonic trimmed lift-drag ratio of at least 4 at approach and landing speeds

(4) A high volumetric efficiency for multiman applications

(5) A body shape that would show potential for entry at superorbital velocities with the possible use of a refurbishable ablation approach to heat protection

(6) A vehicle that is statically stable and controllable over the operational ranges of attitudes and Mach numbers within the sensible atmosphere

After screening the available lifting-body information at the time the study was initiated (early 1962), it was found that no shape under consideration showed promise of meeting all the chosen research guidelines of this study without significant modification. Consequently, a new body designated HL-10 (horizontal lander 10) was designed. The basic body (fig. 1) is highly swept to reduce the convective heating rates on the leading edge, and the blunt nose has a relatively small radius to localize the radiative heat inputs during high-speed entry. Longitudinal curvature of the lower surface was intended to provide stable hypersonic trim at $L/D \approx 1$ without elevon deflection. The combination of upper- and lower-surface curvature was selected to provide gradual boattailing in order to reduce subsonic base drag, to aid in avoiding transonic stability problems, and to provide the desired center of usable volume.

Elevons were added to the basic body for longitudinal and lateral aerodynamic control. (See fig. 2.) The hinge lines of the elevons were swept forward so that the control forces at hypersonic speeds would be in a plane that passed almost through the center of gravity. Therefore, the adverse yaw due to roll control was essentially removed. After preliminary tests at hypersonic and subsonic speeds (refs. 5 to 7), a fin arrangement was established for use with the basic body. This configuration, shown in figure 2, is designated the basic vehicle in this report.

CAMBER EFFECTS

In order to achieve stable hypersonic trim at $L/D \approx 1$ without elevon deflection, the proper combination of lower-surface longitudinal curvature and center-of-gravity location must be achieved. This curvature, or camber, affects the vehicle capabilities over the entire speed range. The basic vehicle with zero and with about 2.5-percent negative camber was used in the studies to ascertain the effects of vehicle camber on several parameters, with emphasis upon the subsonic and hypersonic speeds.

The results of these studies are summarized in table I along with the basic guidelines and several other considerations. Checkmarks indicate that the vehicle exhibited an advantage in the particular guideline or consideration checked. At hypersonic speeds (ref. 7), the negative-cambered vehicle trimmed with $\delta_e = 0^\circ$ at $L/D \approx 1$; with negative elevon deflection angles it achieved a trimmed C_L value of approximately 0.5. By comparison, Charles L. Ladson found that the symmetrical vehicle, with the same center-of-gravity location, had much lower trim-angle-of-attack capability and for a given value of hypersonic L/D had a lower value of C_L (unpublished results from Langley 11-inch hypersonic tunnel). From the results of heating studies conducted by James C. Dunavant and Philip E. Everhart (ref. 8 and unpublished calculations), it was determined that both the shape change and lower C_L resulted in higher heating rates and heat loads for the symmetrical version. The one possible exception might be at maximum L/D where the elevon deflection of the symmetrical version is 0° and the local elevon heating rates may be lower than those of the positively deflected elevons on the negative-cambered vehicle. Throughout the supersonic speed range, there was no distinct advantage of either the symmetrical or cambered vehicle. At subsonic speeds, the symmetrical vehicle achieves a given lift at an angle of attack lower than that of the negative-cambered vehicle (ref. 6). However, the near-neutral longitudinal stability and the greater susceptibility to flow separation from the upper surface of the symmetrical version places the advantage upon the negative-cambered vehicle. Because the negative-cambered vehicle exhibited a better possibility of meeting the basic guidelines, most of the detailed and comprehensive studies have been carried out on this version; throughout the remainder of this paper only the negative-cambered version will be considered.

MACH NUMBER EFFECTS

The performance and stability characteristics of the basic HL-10 vehicle (fig. 3) were measured throughout the speed range from subsonic to hypersonic (refs. 6, 7, and 9 to 14) in various Langley facilities. In figure 3 the open symbols denote results obtained in air; the half-solid symbols, in nitrogen; and the solid symbols, in helium. The values of the trimmed maximum L/D are shown in the top plot of the figure. The second plot of the figure shows maximum and minimum trimmed lift coefficients obtained at negative and positive elevon deflection angles, respectively. These values of C_L, are dependent upon the test elevon deflection angles and angles of attack. At subsonic speeds the negative elevon deflection angles of the tests were less than the values envisioned for actual operation and the available positive trimmed values of C_L would be higher than those presented. At the transonic and low-supersonic speeds, the trimmed lift was limited by the test angle-of-attack range in the facility and/or the elevon deflection angles of the tests. In the bottom plot of figure 3 are the minimum values of C_{n_β} measured throughout the angle-of-attack range at each Mach number.

For the basic HL-10 (circular symbols) the trimmed maximum L/D decreased from about 1.26 at $M = 6.8$ to about 1 at $M = 20$ primarily as a consequence of increased drag; this is discussed later in this paper. The maximum L/D at $M = 20$ in helium was 1.1 and was in good agreement with the Mach 20 nitrogen data obtained in the Langley hotshot tunnel. The slightly higher L/D in helium is associated in part with the higher Reynolds number of the helium tests. This test Reynolds number is approximately equal to the Reynolds number at Mach 20 during a 3g entry ($1\,g = 9.81$ m/sec^2) from a low-altitude orbit.

The results in the bottom plot of figure 3 also show that with the basic vehicle a region of directional instability occurred at low-supersonic speeds. Unfortunately, this negative C_{n_β} occurred in the angle-of-attack range from about 20° to 30° which includes maximum L/D. Although a small amount of negative C_{n_β} can be tolerated for some configurations, basic HL-10 simulator studies with a pilot in the loop have shown that unsatisfactory handling qualities result; therefore, the necessary steps were taken to provide directional stability throughout the operating region. As might be expected, the effectiveness of the center fin was quite low at these Mach numbers at angles of attack in excess of about 25°. Consequently, the major improvement in C_{n_β} was accomplished by configuring the tip fins. In general, tip-fin modifications such as increased area or toe-in angle to increase supersonic C_{n_β} also reduced the trimmed L/D at subsonic speeds. In figure 4 are shown some of these L/D values. The basic-body—center-fin configuration trimmed with $\delta_e = 0°$ at approximately the angle of attack for maximum L/D. The basic tip fins contributed a negative C_m increment that had to be trimmed out by elevon deflection and contributed to the decrease in trimmed L/D. These values for the basic HL-10 were obtained by using a 16-inch model at $R_l \approx 3.5 \times 10^6$ (ref. 11).

Before the discussion of figure 4 is completed, it is instructive to touch briefly upon the comprehensive program carried out to evaluate various concepts for providing supersonic and hypersonic directional stability without reducing the trimmed subsonic performance. Figure 5 shows some of the fins evaluated during this program (refs. 5 to 7, 9 to 12, 14, and 15). Ventral fins, while achieving the high-speed positive C_{n_β}, create local heating problems during entry and ground-clearance problems during landing that complicate the vehicle design. Lower surfaces with dihedral or thickened body leading edges aft of the center of gravity of the vehicle were examined but did not provide the C_{n_β} increments to achieve directional stability. Various types of dorsal tip fins were tested including variations in fin area and fin roll-out and toe-in angles for both single- and double-panel tip fins. The best compromise of supersonic C_{n_β} and low-speed trimmed L/D was achieved by using larger area tip fins with reduced toe-in and roll-out angles (modified version shown in figs. 5 and 6) and a larger center fin. The center dorsal fin and tip fins have been designated E_2 (ref. 16) and I_4 (ref. 14), respectively. The fin modifications had little effect on the subsonic pitching moments, and as shown in figure 4 the maximum trimmed L/D was not reduced from that for the basic vehicle (ref. 17). The tests of the modified vehicle were made with a 30-inch (76.2 cm) model at $R_l \approx 6 \times 10^6$, and the results are essentially in agreement with results of additional tests made with the 28-foot (8.53 m) version at $R_l \approx 24 \times 10^6$ (ref. 16). For the modified HL-10 C_{n_β} was positive at all angles of attack throughout the Mach number range (fig. 3) including the low supersonic speeds.

More recent subsonic studies with the 30-inch model (unpublished results obtained by Bernard Spencer in the Langley high-speed 7- by 10-foot tunnel) and with the 28-foot (8.53 m) model (ref. 16) have shown that by use of simple movable surfaces or "fixes" on the fins, rudder, and elevons the subsonic maximum trimmed L/D may be substantially increased. These subsonic fixes, shown in figure 6, involve the retraction of an outer-surface tip-fin flap, the retraction of the elevon upper-surface flap, and the convergence of the rudder; the combined effect of these fixes is simply a reduction in base drag. With these subsonic fixes the maximum trimmed L/D at subsonic speeds is 4.6 compared with 3.3 without fixes (figs. 3 and 4). Measurements on the 28-foot version at $R_l \approx 24 \times 10^6$, in general, showed a minor increase in L/D and no change in trim angle or longitudinal stability (ref. 16 and unpublished work of John W. Paulson).

Another aerodynamic problem that has been observed in the lifting-body class of vehicles is a transonic pitch-up within a limited angle-of-attack range. For the basic and modified versions of the HL-10 this limited pitch-up occurred at Mach numbers between about 0.7 and 0.9. A typical example is shown in figure 7 for $M \approx 0.8$ and $\delta_e = 0^\circ$. In the studies of the basic vehicle (ref. 11) it was found that a reduction in the convergence of the upper and lower elevon surfaces constituted a fix that removed the limited pitch-up (left plot in fig. 7). For the modified HL-10, the evaluation of possible transonic fixes was more extensive than for the basic vehicle. From tests conducted by William P. Henderson in the Langley high-speed 7- by 10-foot tunnel it was found that a 20° deflection of upper-surface elevon flaps in combination with a 30°

inward deflection of inner-surface tip-fin flaps (see fig. 6) resulted in substantial improvement of the transonic longitudinal stability characteristics (right plot in fig. 7). The elevon flaps serve a dual role in that they are deflected upward for the transonic fix and are deflected downward to improve the subsonic performance as mentioned previously. It is emphasized that these fixes, both subsonic and transonic, are simple two-position flaps.

For any entry vehicle, the effects of Mach number and Reynolds number variation upon the hypersonic aerodynamic characteristics are a determining factor in the performance of the vehicle during entry. Some results of tests of the HL-10 made at Mach numbers of 6.8 and 10.1 in air and at Mach numbers of about 20 in helium and nitrogen are summarized in figure 8. The majority of these results are for an elevon deflection angle of 0°; consequently, the values of L/D shown are not the maximum achieved, either trimmed or untrimmed. As mentioned before, the reduction in maximum L/D when the Mach number is increased from 6.8 to 20.0 is associated primarily with an increase in drag. This drag increase is due partly to the skin-friction increase at the higher Mach numbers and lower Reynolds numbers. In addition, it is probable that there were higher inviscid induced pressures behind the blunted nose that contributed to an axial-force increase. If under actual flight conditions a loss of one-tenth in L/D for a vehicle with an L/D of 1 were to occur, this would represent a reduction of about 100 nautical miles of the 1 000-nautical-mile lateral-range capability, a value that while not catastrophic must be reckoned with in mission planning.

On the right side of figure 8, the pitching-moment curves indicate a large variation in measured elevon effectiveness with variation in Mach and Reynolds numbers. Large regions of separated flow have been observed in oil-flow studies at Mach 6.8 ahead of the elevons when highly deflected and a similar situation occurs at Mach 20 (ref. 12). For this type of vehicle, the reduction in elevon effectiveness is not actually detrimental from a performance standpoint because the L/D is nearly invariant between the trim values of α achieved at $\delta_e = 30^{\circ}$.

Also included in figure 8 are the calculated results obtained by using Newtonian impact theory. In general, the calculated results are in good agreement with the experimental results at $M = 6.8$ where the flow separation is least.

AERODYNAMIC HEATING

An analysis of the convective heating during entry has been made for the negative-cambered vehicle. Measurements were obtained at a Mach number of 8 and at various Reynolds numbers and angles of attack with and without a roughness band on the nose of the body and were compared with theoretical results (refs. 8 and 18). These data were converted to flight conditions for the portion of a 3g entry from near-earth orbit where maximum convective heating occurs. A representative part of these results is presented in figure 9. A center-line distribution of the lower surface is shown in the left plot of the figure and a spanwise distribution at $x/l = 0.5$ in the right plot. By use of cross-flow concepts the laminar heating distributions (dashed curves) were obtained and were in reasonably good agreement with smooth-model measurements with the exception of those near the leading edge. These leading-edge measurements lie between the cross-flow (dashed curves) and isolated-cylinder (dash-dot curve) theoretical results. The turbulent estimates obtained by using sharp-leading-edge flat-plate concepts are in excellent agreement with the rough-model measurements, a result that may be somewhat fortuitous because of the differences between the theoretical and experimental models.

For this 3g entry, the use of metallic radiators which are, at present, temperature limited to about 50 Btu/ft^2-sec (567×10^3 W/m^2) would have application over large portions of the vehicle if the boundary layer is laminar. In the vicinity of the deflected elevons (solid symbols, fig. 9) a type of transpiration or film cooling could possibly be considered in combination with the metallic radiator. The major question that still prevails, however, is whether the heating would be turbulent or laminar. This one consideration would determine whether the primary thermal-protection system would be a combination of ablative and radiative or entirely ablative for the orbital entry. For entry at velocities well in excess of 26,000 ft/sec (7925 m/sec), at least a major portion of the thermal-protection system must be ablative for both laminar and turbulent heating, and the character of the boundary layer would be reflected primarily in the thermal-protection-system weight and selection of the material used.

The effects of angle of attack and, consequently, L/D variation upon the convective heating during entry from a near-earth orbit are presented in figure 10. On the left side of the figure, the maximum heating rates of the vehicle during entry are presented for two points on the vehicle lower-surface center line ($x/l = 1/8$ and $1/2$). The angles of attack of 52°, 41°, and 26° correspond to maximum lift, L/D = 1, and maximum L/D, respectively. Note that the effects of vehicle attitude upon heating rate are dependent upon the location of the point under consideration - at the forward location ($x/l = 1/8$) the heating rate increases with L/D whereas the reverse trend is noted for the midlength location at angles of attack greater than α at maximum L/D. Additional results for the more rearward stations show trends similar to that of the midlength station. Therefore, it may be concluded that no one point can be taken as a general indication of what is to be expected at various locations over a complex shape. Additional studies, for example, have shown that body shape has a major influence upon the variation of heating rate with L/D or α at various longitudinal body locations.

For these two points on the HL-10 the total-heat-load variation (Btu/ft^2 or W/m^2) with L/D and α for the undershoot case is similar to the heating-rate variations shown in figure 10; however, when the entire vehicle is considered, the results are quite different. On the right side of figure 10 are the integrated total heat loads over the entire vehicle (upper and lower surfaces) for the 3g undershoot entry and for the longer-time overshoot entry. The highest heat load is for the overshoot entry. For this entry, the heat loads at high values of α and C_L are less than those at the lower values of α and C_L for the same values of L/D.

Therefore, for operation of this type of vehicle within a range of values of L/D, it is more attractive from the standpoint of heat loads to operate at high angles of attack and high values of lift.

LOW-SPEED HANDLING QUALITIES

At low speeds some studies of the handling qualities have been conducted by John W. Paulson and George M. Ware with a 60-inch-long (152.4 cm), air-jet-powered, flying, dynamically scaled model (fig. 11) in the Langley full-scale tunnel. This flying model of the modified configuration exhibited good stability and control characteristics to the maximum test angle of attack of 45°, a value well in excess of maximum α required (approximately 25°) for approach, flare, and landing. Unlike several other highly swept delta configurations previously studied, the Dutch roll oscillations were well damped over the α-range for this three-fin configuration. Detailed studies of pilot handling and landing will be undertaken as part of the NASA intercenter flight program on the one-man, B-52 air-launched, Langley HL-10 and Ames M-2F-2 vehicles. The HL-10 configuration used in the flight program is the same as the modified vehicle with fixes discussed herein.

LANDING CHARACTERISTICS

Various studies have been conducted of ground runout characteristics. During the studies of normal ground runout in which twin main skids and a nose wheel were used, a limited-torque nose-gear steering device was developed by Upshur T. Joyner of the Langley Research Center. By use of limited torque in the steering, the side force generated by the nose wheel is also limited. Consequently, the destabilizing yawing moments produced by the nose wheel can be balanced out by the stabilizing moments of the main skids. This device is generally applicable to other configurations using twin-skid—nose-wheel combinations.

Ground-landing and water-landing studies have been conducted with the HL-10 in the Langley impact structures facility by Lloyd J. Fisher and Sandy M. Stubbs. The normal ground-landing studies using a catapulted, dynamically scaled HL-10 model (fig. 12) revealed no problems peculiar to this particular configuration. Although the HL-10 configuration was used in these landing studies, many of the results obtained are applicable to some horizontal-landing vehicles. One finding of interest which is applicable to many horizontal landers that employ twin skids, a nose wheel, and strain straps for shock absorption is the influence of vehicle roll attitude at touchdown upon the slideout characteristics. With the vehicle rolled at touchdown, the difference in the stretch of the strain straps on the two main gears caused the vehicle to retain a rolled attitude at the start of ground slideout. The differential loading on the main skids caused the vehicle to yaw and to produce a side force from the nose wheel. If the combined effects of the roll are excessive, the vehicle will tumble. In the study the nose gear was not steerable and, consequently, the realistic limit of roll attitude at touchdown followed by steering during runout could not be established. Use of a steerable limited-torque nose wheel can reduce the influence of roll attitude at touchdown upon slideout characteristics.

Emergency landings have also been studied. With the landing gear up, landings on a prepared surface were simulated and appear highly feasible, particularly when a small drogue parachute is deployed just prior to touchdown to eliminate small inadvertent yawing attitudes. As expected, horizontal water landings at simulated touchdown velocities in the vicinity of 150 knots resulted in what appeared to be uncontrollable vehicle gyrations. Although the occupants may survive this mode of water landing, it surely does not represent an attractive prospect even for an emergency letdown procedure. An emergency water-landing technique has been developed and requires a parachute letdown so that the vehicle enters the water at a near-vertical attitude (about 70°) (fig. 13). By virtue of the gradual increase in submerged volume as the vehicle penetrates deeper into the water, the deceleration builds up gradually and peaks at about 3g. Both fore and aft entries into the water were studied. The aft entry appears more desirable inasmuch as the deceleration is directed aft and can be accommodated by the restraint systems used during atmospheric entry. Following the deepest water penetration, the vehicle rises and at the same time undergoes a smooth transition in attitude, coming to rest at a near-level attitude on the water surface. The penalty to provide such a letdown system for a 11 000-pound, 28-foot (4990 kg, 8.53 m) vehicle has been estimated to be about 3 percent of its mass at landing.

ADDITIONAL RESEARCH

Recently, heat-transfer and pressure distributions were obtained at a Mach number of about 20 in the Langley hotshot tunnel. Mach 10 force measurements over a range of Reynolds numbers are being taken to aid in the evaluations of flow-separation effects and performance, control effectiveness, and stability. Mach 10 pressure measurements should be made to compare with the higher enthalpy Mach 20 results.

Internal layouts of the HL-10 and other lifting-body shapes have shown that in some instances the use of a protruding canopy is advantageous in the design of a minimum-size vehicle (about three or less occupants) in which acceptable visibility and minimum internal heights are generally difficult to achieve. The effects of several types of protruding canopies upon the aerodynamic characteristics are being studied with emphasis upon subsonic trimmed performance and low-supersonic-speed directional stability. Aerodynamic heating of the canopies with the HL-10 at angles of attack for maximum L/D and higher should be included in the overall canopy evaluation.

Additional studies to develop emergency horizontal-water-landing (ditching) techniques using auxiliary devices are underway. These devices are intended to penetrate the water and remain submerged while decelerating the vehicle with restricted motions.

CONCLUDING REMARKS

Studies have been made at the Langley Research Center of a class of advanced manned lifting entry vehicle with a hypersonic maximum lift-drag ratio (L/D) slightly in excess of 1. From these studies has emerged a configuration designated HL-10 that incorporates the design criteria established during the early phases of the study. This configuration has been used as the focal point of the study. Many problems, their possible solutions, and compromises have been revealed in this study; several in the areas of aerodynamics, heating, handling qualities, and ground and water landing have been discussed herein. Some of these are not peculiar to this specific class of vehicle but apply to other classes as well.

It has been demonstrated that a promising class of vehicle with L/D slightly greater than 1 can be designed within the chosen guidelines of this study. Static stability and control are achieved throughout the speed range from subsonic to hypersonic. Care must be exercised to achieve directional stability at low supersonic speeds if significant penalties are to be avoided in subsonic trimmed performance. Longitudinal stability problems at high subsonic speeds may be resolved and subsonic trimmed performance increased by use of simple aerodynamic fixes. Heat loads during entry may be reduced by operation at lift coefficients for angles of attack in excess of that for hypersonic maximum L/D. The problems of low-speed handling and horizontal ground landing do not appear to be severe; emergency water landings appear to be feasible by use of a near-vertical-attitude water-entry technique.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., August 11, 1965.

REFERENCES

1. Love, E. S.; and Pritchard, E. B.: A Look at Manned Entry at Circular to Hyperbolic Velocities. 2nd Manned Space Flight Meeting (Dallas, Texas), Am. Inst. Aeron. Astronaut., Apr. 1963, pp. 167-180.

2. Love, Eugene S.: Factors Influencing Configuration and Performance of Multipurpose Manned Entry Vehicles. J. Spacecraft Rockets, vol. 1, no. 1, Jan.-Feb. 1964, pp. 3-12.

3. Syvertson, C. A.; Swenson, B. L.; Anderson, J. L.; and Kenyon, G. C.: Some Considerations of the Performance of a Maneuverable, Lifting-Body, Entry Vehicle. Vol. 16, pt. one of Advances in the Astronautical Sciences, Norman V. Petersen, ed., Western Periodicals Co. (N. Hollywood, Calif.), c.1963, pp. 898-918.

4. Mechtly, E. A.: The International System of Units - Physical Constants and Conversion Factors. NASA SP-7012, 1964.

5. Rainey, Robert W.; and Ladson, Charles L.: Preliminary Aerodynamic Characteristics of a Manned Lifting Entry Vehicle at a Mach Number of 6.8. NASA TM X-844, 1963.

6. Ware, George M.: Aerodynamic Characteristics of Models of Two Thick 74° Delta Manned Lifting Entry Vehicles at Low-Subsonic Speeds. NASA TM X-914, 1964.

7. Ladson, Charles L.: Aerodynamic Characteristics of a Manned Lifting Entry Vehicle at a Mach Number of 6.8. NASA TM X-915, 1964.

8. Dunavant, James C.; and Everhart, Philip E.: Investigation of the Heat Transfer to the HL-10 Manned Lifting Entry Vehicle at a Mach Number of 8. NASA TM X-998, 1964.

9. Campbell, James F.; and McShera, John T., Jr.: Stability and Control Characteristics From Mach Number 1.50 to 2.86 of a Model of a Manned Lifting Entry Vehicle. NASA TM X-1117, 1965.

10. McShera, John T., Jr.; and Campbell, James F.: Stability and Control Characteristics of a Manned Lifting Entry Vehicle at Mach Numbers From 2.29 to 4.63. NASA TM X-1019, 1964.

11. Rainey, Robert W.; and Ladson, Charles L.: Aerodynamic Characteristics of a Manned Lifting Entry Vehicle at Mach Numbers From 0.2 to 1.2. NASA TM X-1015, 1964.

12. Johnston, Patrick J.: Stability Characteristics of a Manned Lifting Entry Vehicle at a Mach Number of 20.3 in Helium. NASA TM X-1156, 1965.

13. Harris, Julius E.: Longitudinal Aerodynamic Characteristics of a Manned Lifting Entry Vehicle at a Mach Number of 19.7. NASA TM X-1080, 1965.

14. Ladson, Charles L.: Aerodynamic Characteristics of a Manned Lifting Entry Vehicle With Modified Tip Fins at Mach 6.8. NASA TM X-1158, 1965.

15. Silvers, H. Norman; and Campbell, James F.: Stability Characteristics of a Manned Lifting Entry Vehicle With Various Fins at Mach Numbers From 1.50 to 2.86. NASA TM X-1161, 1965.

16. Ware, George M.: Full-Scale Wind-Tunnel Investigation of the Aerodynamic Characteristics of the HL-10 Manned Lifting Entry Vehicle. NASA TM X-1160, 1965.

17. Spencer, Bernard, Jr.: An Investigation of Methods of Improving Subsonic Performance of a Manned Lifting Entry Vehicle. NASA TM X-1157, 1965.

18. Everhart, Philip E.; and Hamilton, H. Harris: Investigation of Roughness-Induced Turbulent Heating to the HL-10 Manned Lifting Entry Vehicle at a Mach Number of 8. NASA TM X-1101, 1965.

TABLE I.- CAMBER EFFECTS

	Vehicle with negative camber	Symmetrical vehicle
Research guidelines:		
Hypersonic $L/D \approx 1$, $\delta_e = 0^\circ$	✓	
Hypersonic high trimmed C_L	✓	
Subsonic trimmed $L/D \geqq 4$	✓	✓
High volumetric efficiency	✓	✓
Promising body shape	✓	✓
Stable and controllable	✓	
Additional considerations:		
Lower heating rates and loads	✓	✓(local)
Lower α for subsonic C_L		✓
Reduced subsonic flow separation	✓	

UNCLASSIFIED

[redacted]

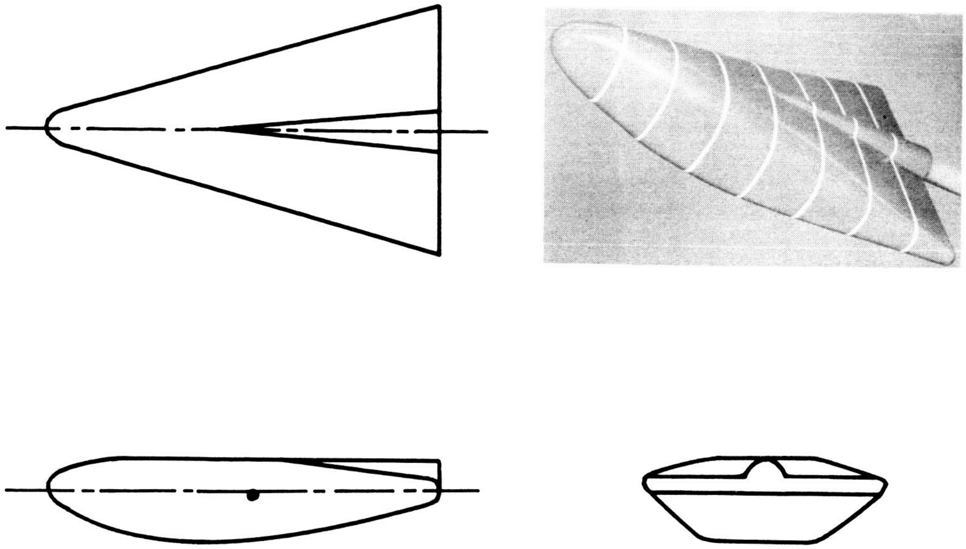


Figure 1.- Basic body.

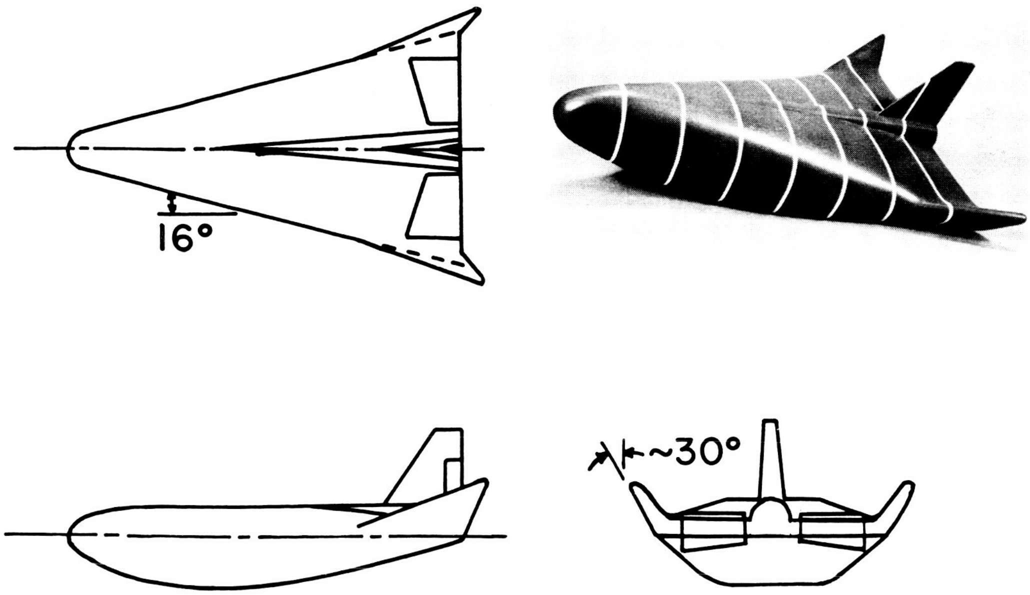


Figure 2.- Basic vehicle (basic body with elevons and fins).

[redacted]

UNCLASSIFIED

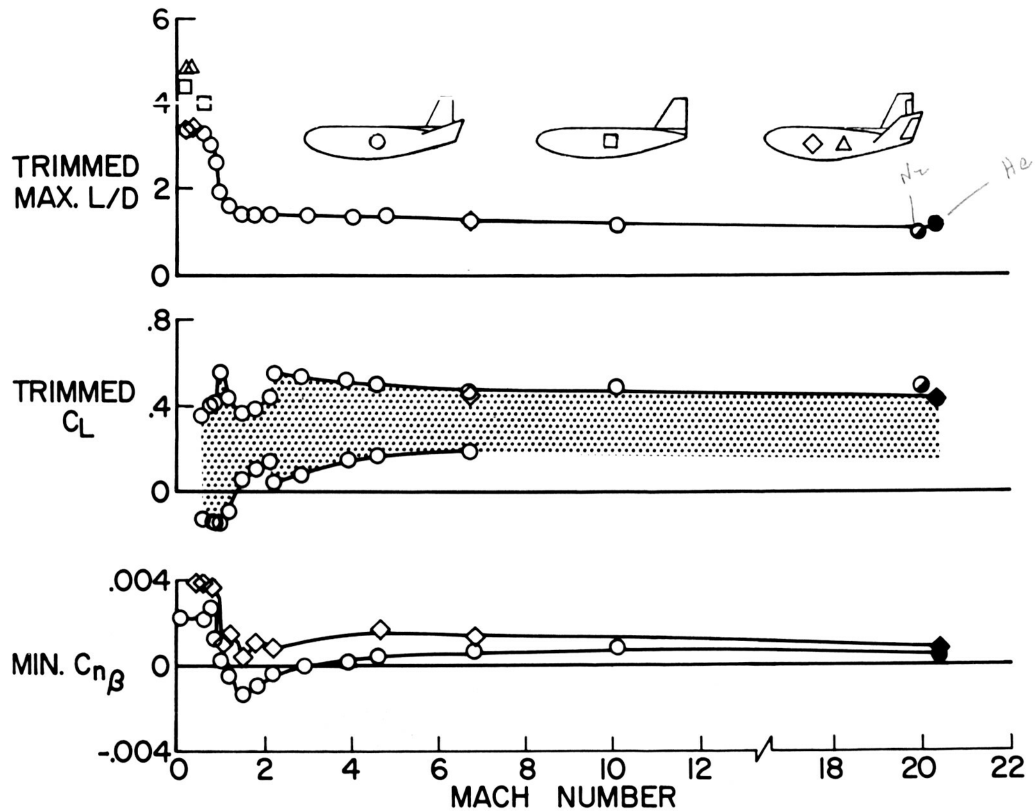
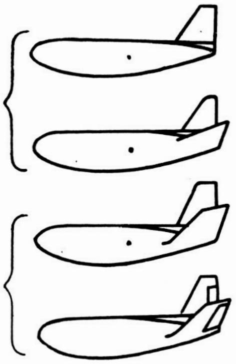


Figure 3.- HL-10 characteristics.



	UNTRIMMED L/D ($\delta_e = 0°$)	TRIMMED L/D
Basic vehicle	4.6	4.4
Basic vehicle	4.4	≈3.3
Modified vehicle	4.4	3.3
Modified vehicle	5.1	4.6

Figure 4.- Subsonic lift-drag ratios.

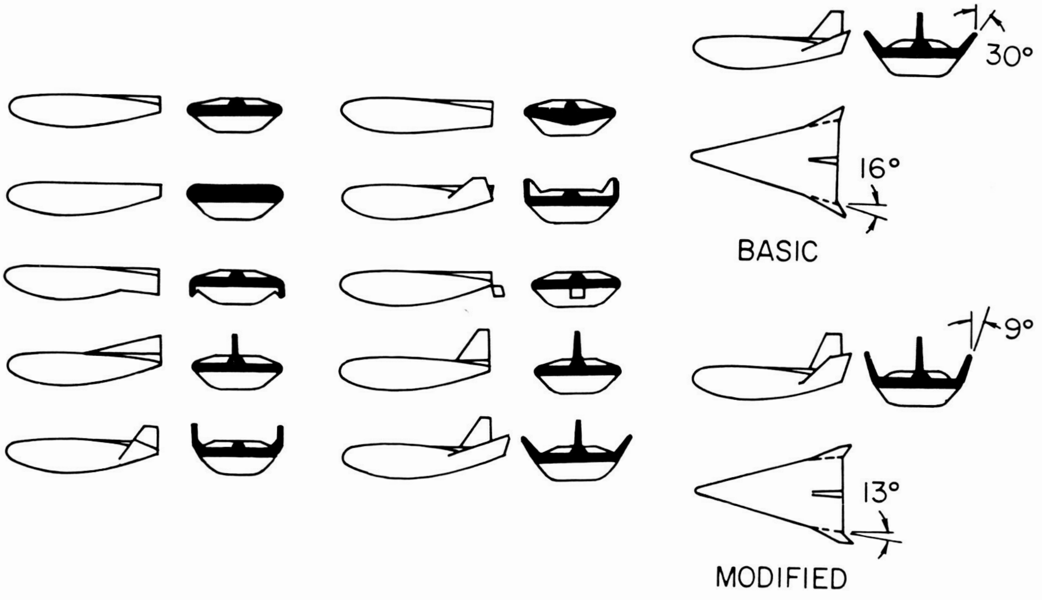
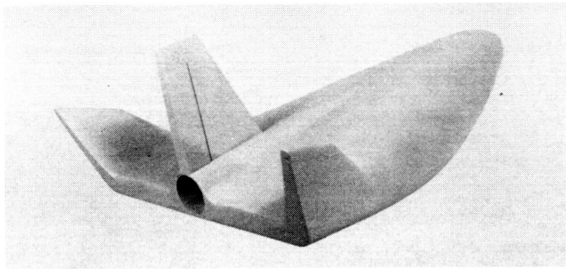
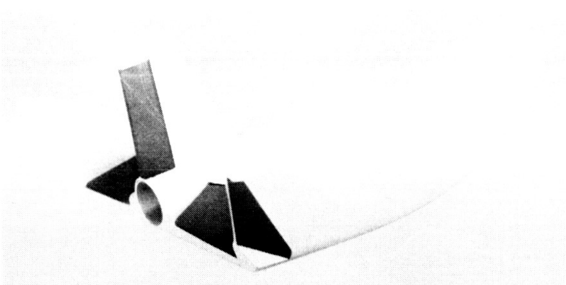


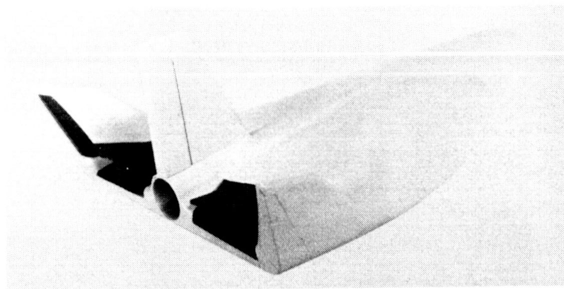
Figure 5.- Some of the fin arrangements used in the study.



Without fixes

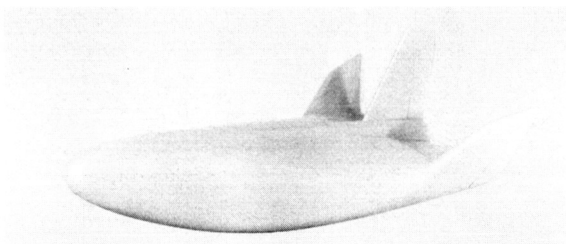


With subsonic fixes

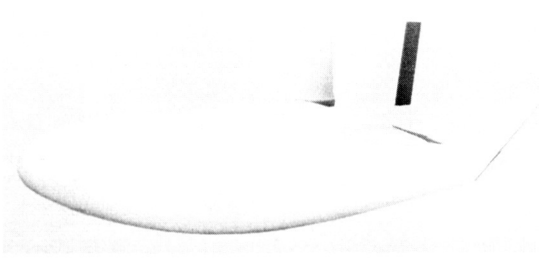


With transonic fixes

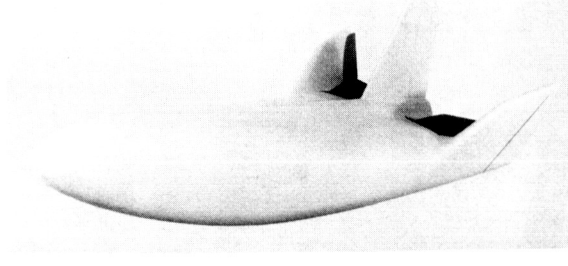
(a) Three-quarter rear view. L-65-178



Without fixes



With subsonic fixes



With transonic fixes

(b) Three-quarter front view.

Figure 6.- Modified vehicle configurations. L-65-179

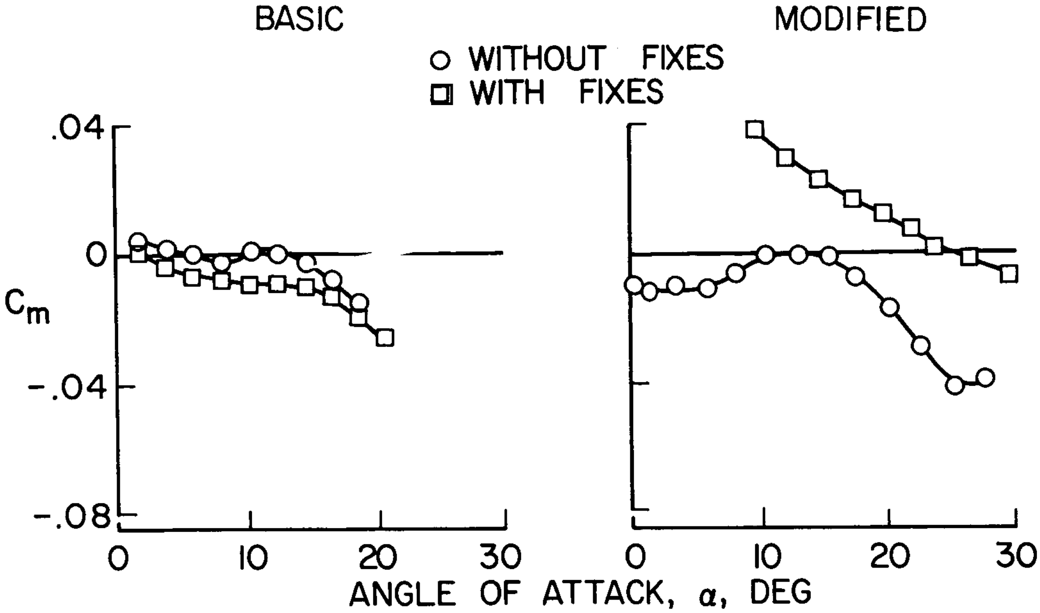


Figure 7.- Transonic longitudinal stability. $M \approx 0.8$; $\delta_e = 0^0$.

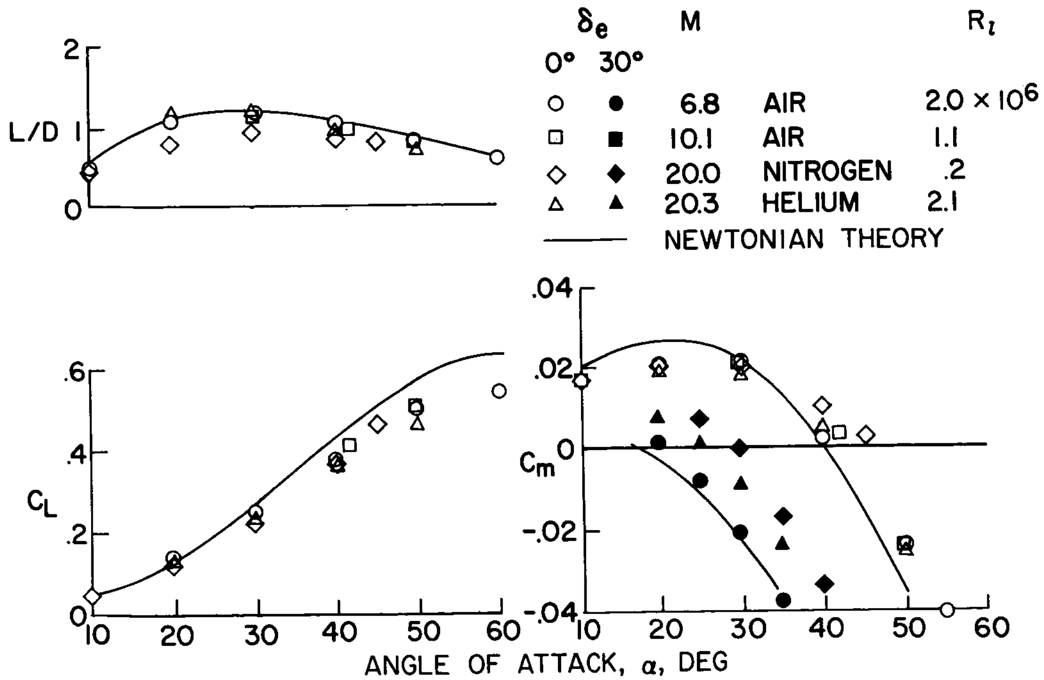


Figure 8.- HL-10 hypersonic aerodynamic characteristics.

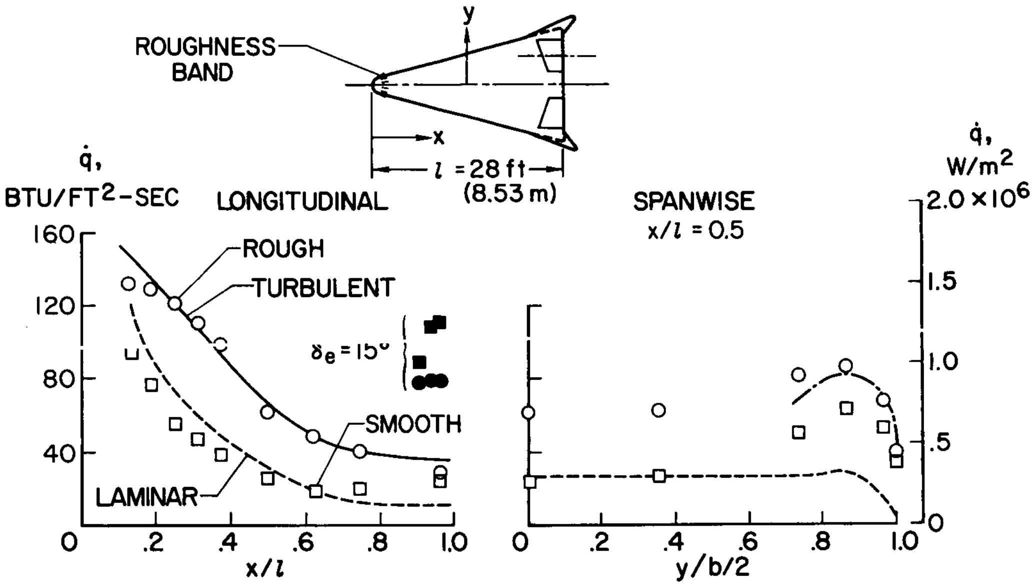


Figure 9.- Maximum heating distributions of HL-10 during 3g entry. V_E = 25 500 ft/sec (7772.4 m/sec); $\alpha = 30^0$; $\delta_e = 0^0$.

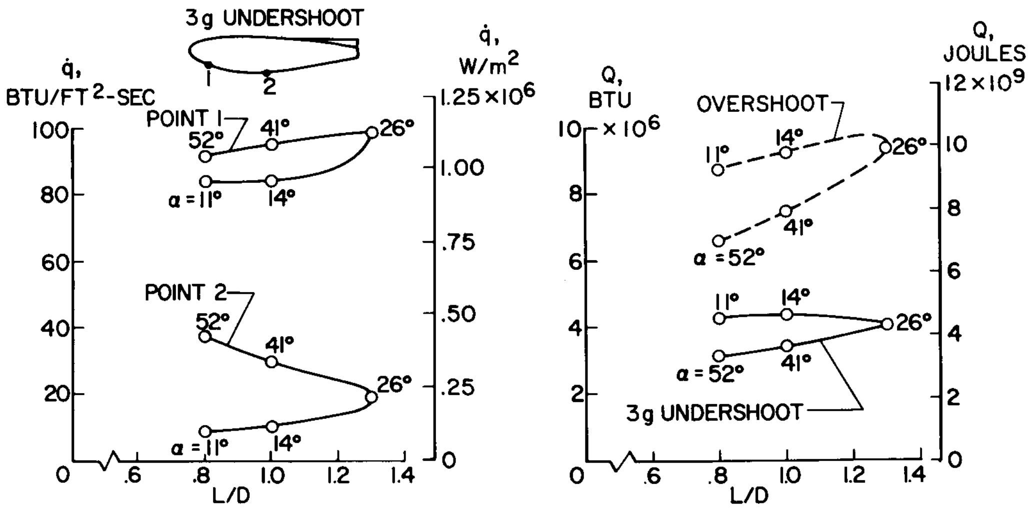


Figure 10.- Heating of HL-10 during 3g entry. V_E = 25 500 ft/sec (7772.4 m/sec).

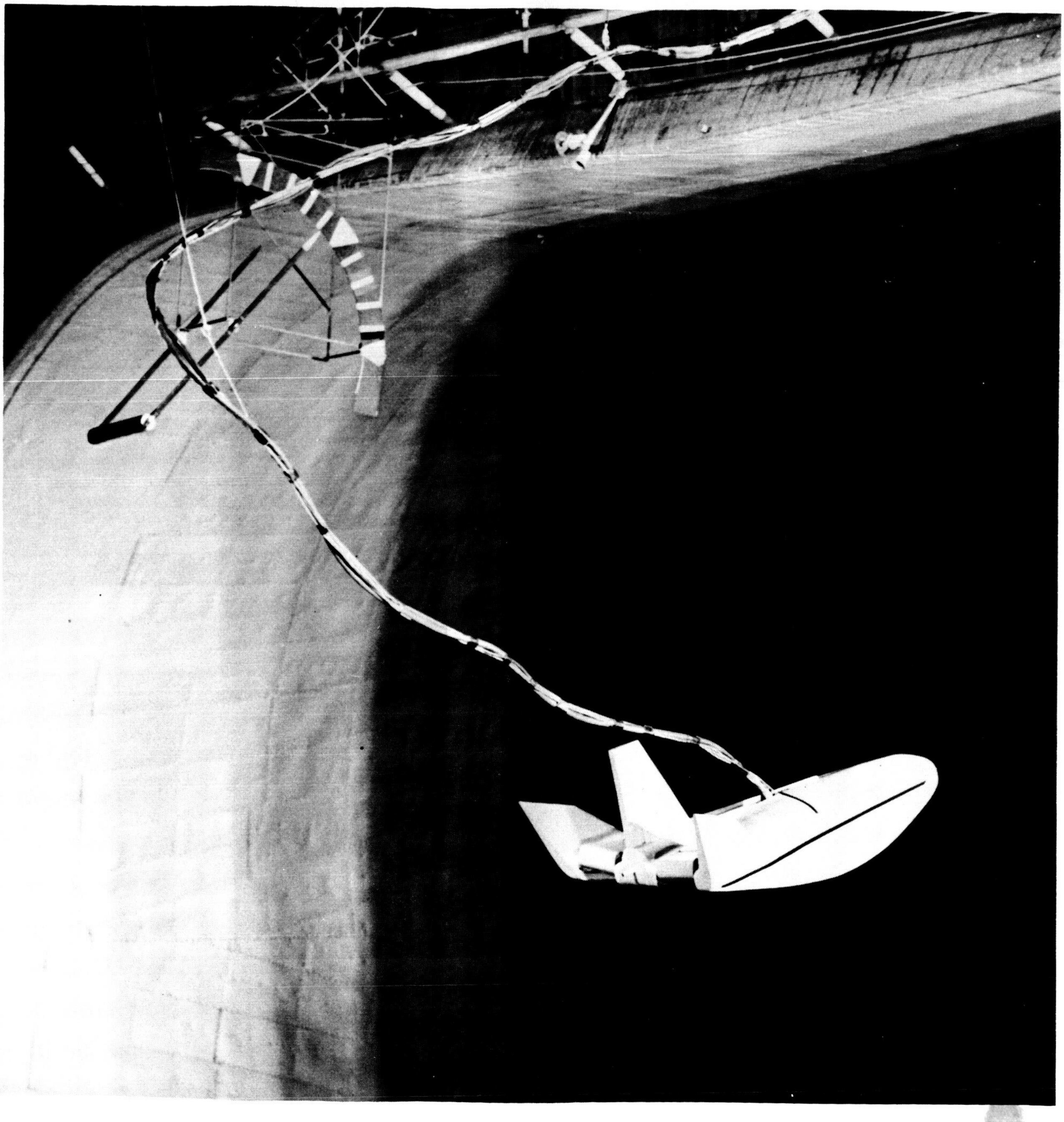


Figure 11.- HL-10 model flying in Langley full-scale tunnel. L-64-11,189

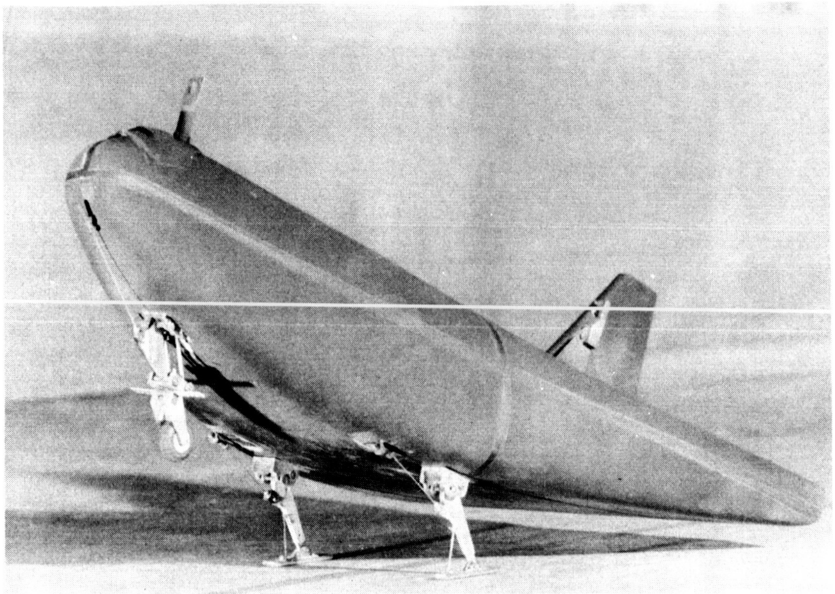


Figure 12.- HL-10 model used in ground-landing studies. L-65-3519

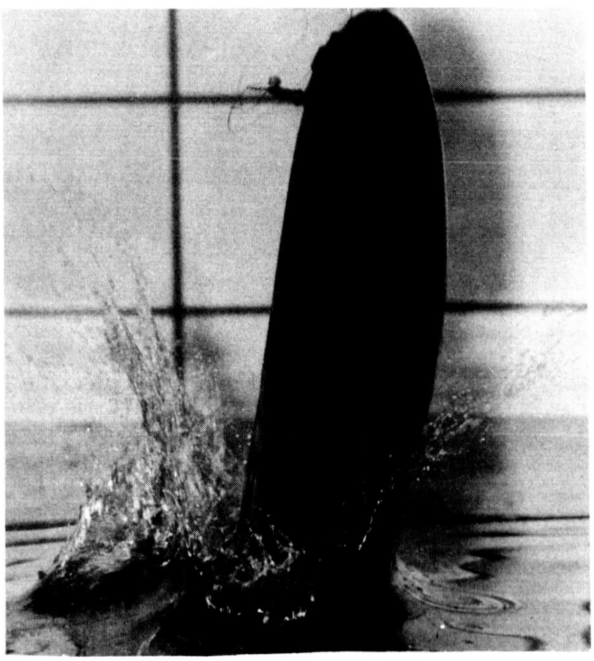


Figure 13.- Near-vertical HL-10 water landing. L-65-3518

NASA-Langley, 1965 | L-4634

~~CONFIDENTIAL~~

UNCLASSIFIED

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Technical information generated in connection with a NASA contract or grant and released under NASA auspices.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

TECHNICAL REPRINTS: Information derived from NASA activities and initially published in the form of journal articles.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities but not necessarily reporting the results of individual NASA-programmed scientific efforts. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546

UNCLASSIFIED

~~CONFIDENTIAL~~